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# Human Robotics Interaction Army Technology Objective Raven Small Unmanned Aerial Vehicle Task Analysis and Modeling

by Regina A. Pomranky

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**14. ABSTRACT**
A Family of Systems (FoS) is being developed that will comprise the Army's Future Combat Systems (FCS). In an effort to determine the most effective and efficient way to integrate the diverse but related new systems within the future force, the U.S. Army Research Laboratory is developing an operator workload model of FCS FoS operations. This development is part of the Human Robotics Interaction Army Technology Objective in which Soldier workload models of individual systems are being developed with the intent of integrating them into one all-encompassing model. This Improved Performance Integration Research Tool (IMPRINT) model will enable the investigation of individual to overall workload and will examine how these Soldier-systems can effectively combine their efforts to more efficiently accomplish a mission. FCS FoS will rely heavily on unmanned systems such as unmanned ground vehicles and unmanned aerial vehicles (UAVs) to assume such roles as intelligence gatherer, perimeter security, vehicle reconnaissance, reconnaissance and surveillance for initial entry forces, call for fire, battle damage assessment, etc. In fact, at least 11 types of UAVs were committed to Operation Iraqi Freedom, demonstrating the current need for the capabilities that UAVs can provide. In order to understand the combination of the capabilities of a UAV with other system capabilities within a commander's arsenal, a model of operator workload was developed for the Raven small UAV (SUAV). This project describes the detailed task analysis used to build an IMPRINT model and the initial model runs for determining the workload associated with operating the Raven SUAV with a two-person team.

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Future Combat System; human performance; task and workload modeling; unmanned aerial vehicles

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# 1. Introduction

Future combat will rely heavily on unmanned aerial vehicles (UAVs) to assume such roles as intelligence gatherer, perimeter security, vehicle reconnaissance, reconnaissance and surveillance for initial entry forces, call for fire, battle damage assessment (BDA), etc. In fact, at least 11 types of UAVs were committed to Operation Iraqi Freedom, demonstrating the current need for the capabilities that UAVs can provide. Army UAVs of the future are hoped to enhance platoon to task force combat commanders' intelligence, surveillance, and reconnaissance, targeting, BDA, and lethal operations capabilities.

Current combat operations in Iraq are taking place in often chaotic and confined urban terrain where the use of a small, highly maneuverable UAV is in high demand. This demand is also needed in Afghanistan where the enemy hides in mountains and caves often not penetrable by Soldiers on foot. The Raven small UAV (SUAV) is currently being used in Operation Enduring Freedom and Operation Iraqi Freedom with great success. Raven has the ability to fly over or loiter around potential areas of interest, providing an air picture for commanders and troops while reducing the risk of loss of life.

## 1.1 System Description

The Raven SUAV is a man-portable, hand-launched UAV that transmits live airborne video images and location information and allows operators the ability to perform such missions as reconnaissance, surveillance, and remote monitoring. A Raven air vehicle has a wing span of 55 inches and a length of 36 inches (see figure 1). It has a direct drive electric motor, which is battery powered and has low visual, acoustic, and thermal signatures. With a rechargeable lithium ion (Li-ion) battery, the Raven will fly for approximately 60 to 90 minutes, and with a lithium sulfur dioxide ($LiSO_2$) battery, it will fly approximately 80 to 110 minutes. The structure is modular and is made of Kevlar[1] composite. Each Raven weighs 4.2 pounds with the payload (6.5 ounces) (AeroVironment, 2004).

A Raven system generally consists of two to four aircraft, one electro-optical (EO) camera payload nose (front and side look), one infrared (IR) camera payload nose (front look), one IR camera payload nose (side look), one to two ground control units (GCU), and one remote video terminal (RVT) (optional).

[1]Kevlar is a registered trademark of E. I. DuPont de Nemours, Inc.

Figure 1.  Raven SUAV.

These components can be assembled in less than 3 minutes and are stored and transported in two cases slightly larger than briefcase size (19-1/8 by 12-1/4 by 4-3/4 inches), which are water, dust, sand, and dirt proof.  With the aircraft components, the wing case weighs 5 pounds and the fuselage case weighs 6 pounds.

The Raven SUAV has both an EO and IR camera within the two provided noses of the aircraft.

The EO payload nose has both side and front look views.  There are two IR payload noses.  One has a forward look view and the other has a side look view.  The forward look view is at a 45-degree angle to the ground.  At 500 feet above ground level (AGL), the video clarity begins to degrade (AeroVironment, 2004).

The operating altitude for the Raven is 150 to 1000 feet AGL with an ideal low altitude of 100 feet.  The Raven has a cruising speed of 30 miles per hour and a range of 10 kilometers line of sight.  It has a climbing rate of 900 feet/minute at 2000 feet AGL and a turning rate (360°) of 24 seconds.  There are four channels/frequencies on the Raven SUAV to allow for operation of multiple systems in proximity.  The GCUs are used to control the air vehicle, enter waypoints, and receive video from the payload in the air vehicle.  The RVT is used as a monitor only.  It receives real-time video (within 5 to 10 kilometers) but has no functionality to control the air vehicle or mission parameters (AeroVironment, 2004).

Figure 2.  Raven ground control unit.

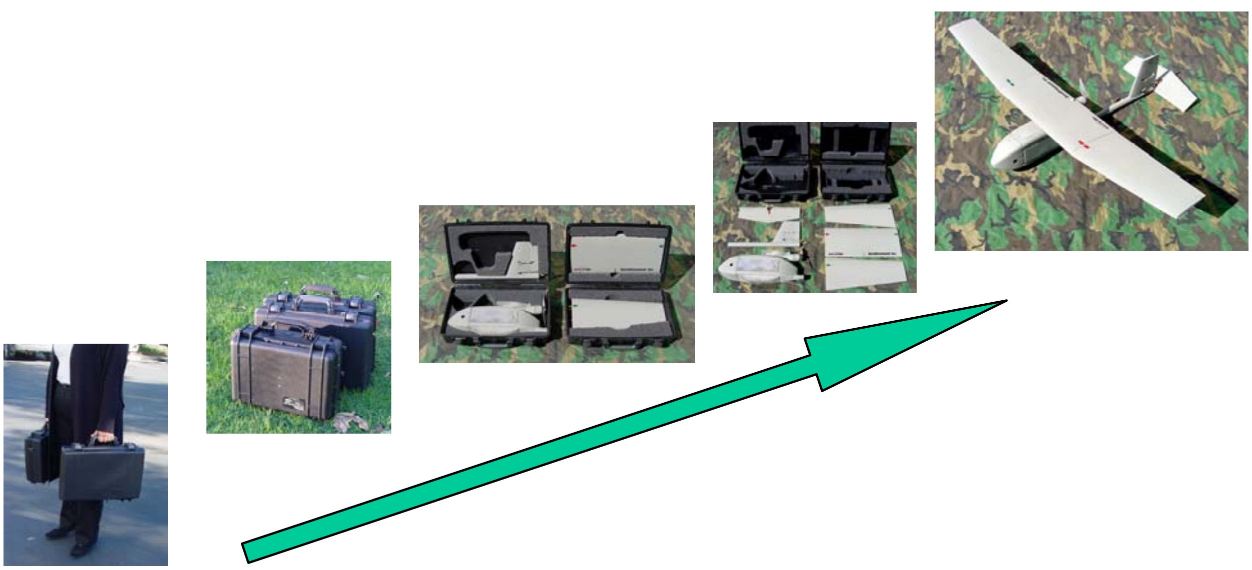

Figure 3.  Assembly of the raven SUAV.

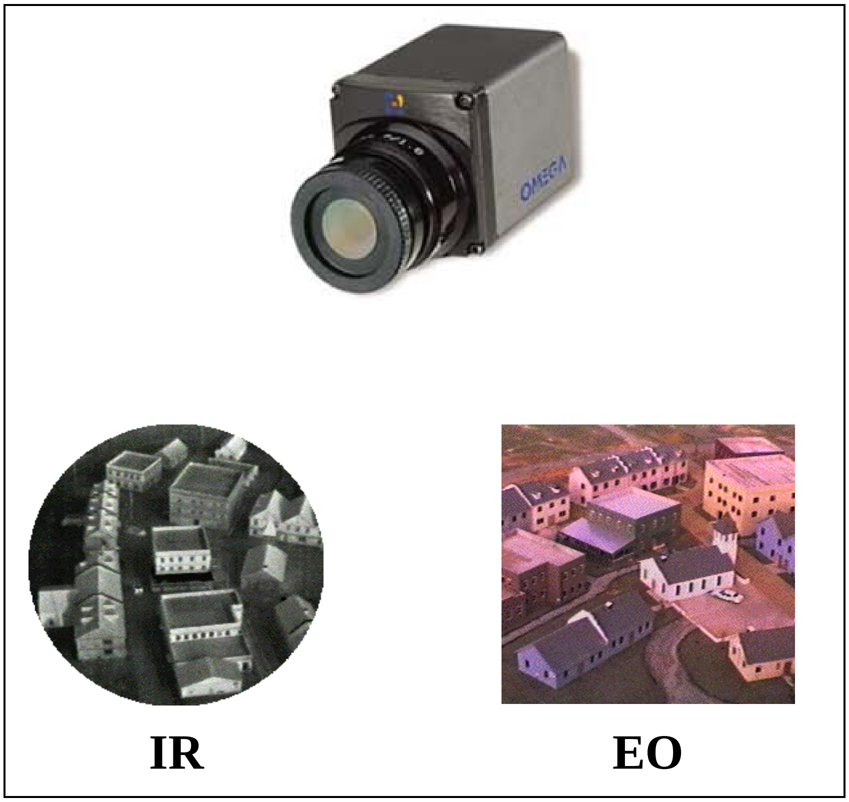


Figure 4. Raven camera with IR and EO video.

Table 1. Camera characteristics.

| | EO | IR |
|---|---|---|
| Pixels | 768H X 494V | 106H X 120V |
| Payload Nose Weight | 6.2 oz | 6.5 oz |

Although the Raven aircraft can be operated by one Soldier if necessary, it is typically operated by a two-person team consisting of an aircraft controller and a mission controller. The aircraft controller is responsible for the flight path and the altitude of the aircraft using the toggle, joystick, and auto-land buttons on the operator controller. The mission controller is generally responsible for the entry of waypoints, monitoring system status and live video and monitoring/editing real-time flight information. This project describes the detailed task analysis used to build an Improved Performance Research Integration Tool (IMPRINT) model and the initial model runs for determining the workload associated with operating the Raven SUAV with a two-person team.

# 2. Method

Modeling and simulation allow researchers to establish a relationship between events and behaviors while evaluating human performance without actually using human participants. In fact, the strength of modeling and simulation is the ability to conduct research on pre-existing systems such as those proposed for the Future Combat Systems (FCS). This project describes the detailed task analysis used to build an IMPRINT model and the initial model runs for determining the workload associated with operating the Raven SUAV with a two-person team.

## 2.1 Modeling Approach

The Human Research and Engineering Directorate of the U.S. Army Research Laboratory has developed a modeling tool called IMPRINT to assess task and workload demands and evaluate human and system performance (Allender, Kelley, Archer, & Adkins, 1994). IMPRINT uses workload theory, which states that every task a human performs requires some demand on attentional resources. IMPRINT is used to assign values to the amount of effort used to perform a task (Mitchell, 2000).

## 2.2 Development of Procedures

The procedures used involved first performing a task analysis of Raven SUAV operators, which resulted in a detailed task list, and then using IMPRINT to develop a graphical representation of the flow of tasks as well as the assignment of workload values for each task. Finally, the Raven SUAV model was executed in IMPRINT to examine individual workload during the performance of different Raven tasks to ensure that workload was accurately portrayed. This IMPRINT model will be combined with various FCS models to examine the workload required of Soldiers in the completion of a mission and how it affects overall performance.

### 2.2.1 Task Analysis

A task analysis of the Raven SUAV was performed. Tasks for the aircraft and mission controllers were obtained from the Operator's Manual, Version 2.2 (AeroVironment, 2004). In addition, subject matter experts (SMEs) were observed and interviewed. These SMEs were the Special Operations Command instructors who were well versed in the operation of the Raven SUAV as well as its predecessor, the Pointer UAV. The completed task list consists of nine functions and 195 tasks for the aircraft controller (appendix A, table A-2) and nine functions and 142 tasks for the mission controller (appendix A, table A-3). An existing IMPRINT library of micro-models of UAV operations and infantry squad member operations was also reviewed for tasks and task sequences. Finally, participation in and observation of Raven SUAV training occurred at Yuma Proving Ground, Arizona.

### 2.2.2 Modeling

Advanced IMPRINT was used to develop a model of operator workload for the Raven SUAV. The advanced version of IMPRINT imposes penalties on workload and performance when conflicts arise between and within the resources used. This approach is modeled after Wickens' Multiple Resource Theory (Wickens, 1991). This model will be combined with models of additional systems in order to determine how best the Family of Systems of the FCS will work most efficiently and effectively to accomplish a mission. The Raven SUAV functions and tasks are derived from the task analysis. The Raven SUAV IMPRINT model consists of nine functions: pre-flight, launch, flight modes (manual mode, altitude mode, home mode, loiter mode, and navigating waypoints mode), landing, and post-flight. In order to accomplish these functions, the operator must use certain interfaces such as the toggle or joystick which require the use of attentional resources such as vision and motor. As pre-flight, launch, landing and post-flight functions generally remain consistent from mission to mission, it was necessary to focus on the tasks completed, based on the flight mode in which the UAV was operating. As is the case with any mission, mission planning based on commander's intent will dictate the most effective and efficient use of a system. In the case of the Raven SUAV, the flight mode will be determined during mission planning. For example, if the mission of the UAV is to conduct perimeter security, the navigating waypoints mode will likely be used. However, if the mission is vehicle surveillance, the manual mode will be used. It is important to note that the flight mode can be changed at any time during flight by either the aircraft controller or the mission controller. For this study, the assumptions are that manual mode is most likely to be used, followed by the navigating waypoints mode. It is important to note that the model was designed so that IMPRINT randomly chooses mode based on the probabilities set within the model. The probabilities were set within the model based on input from SMEs to represent the probability of changing to a different mode based on the current mode. For example, if the AV is flying in the navigating waypoints mode, the probability of changing to manual mode would be 40%; altitude mode, 20%; home mode, 10%; and loiter mode, 30%.

In order to operate the Raven, the GCU must be set to one of the available five flight modes: manual mode, altitude mode, navigating waypoints mode, loiter mode, or home mode. A detailed task analysis was performed for each of the five flight modes for both the aircraft controller and the mission controller.

The manual mode of operation allows for full control of the AV to include flight path and altitude. In order to operate the AV in the manual mode, the aircraft controller must continually manipulate the stick and throttle, monitor the flight path of the AV, communicate with the mission controller, and search/scan live video. In addition, upon identification of a potential target, monitoring and communication tasks intensify and a course of action must be determined. The mission controller tasks during the manual mode include continuous monitoring of systems status to include heading of the AV, bearing, battery life, and global positioning systems (GPS) connectivity, search/scan live video, and communication with the aircraft controller. As with the

aircraft controller, the mission controller's tasks of monitoring and communication intensify upon identification of a potential target.

The altitude mode of controlling the AV maintains the operator-commanded altitude while allowing the aircraft controller to have full lateral control of the flight path. Controlling the AV in the altitude mode requires only the continuous manipulation of the stick control to maneuver the AV laterally. No manipulation of the toggle switch is necessary as the altitude mode maintains an operator commanded altitude. All other tasks of both the aircraft controller and the mission controller are the same as when operating in the manual mode.

The navigating waypoints mode allows the operation of the AV to be controlled by pre-programmed waypoints. When the AV is in the navigating waypoints mode, only periodic adjustments of the throttle to control altitude are necessary. As with the altitude mode, all other tasks of the aircraft controller and the mission controller are the same as they are operating in the manual mode.

The loiter mode is used when a pre-set target or a newly identified target is in range. The loiter mode commands the AV to circle counterclockwise around a selected location using the side look camera to view the target. During operation in this mode, the aircraft controller must periodically manipulate the stick control and throttle to correct the flight path as wind and other factors cause the AV to stray. As is the case in the previous modes, all other tasks of the aircraft controller and the mission controller are the same as when they operate in the manual mode.

Finally, the home mode is used to return the AV to the home waypoint. The location where the GPS satellites were originally acquired is automatically set as the home waypoint. This location is generally the spot in which the pre-flight inspection was conducted. However, the home waypoint can be manually set to a different location if desired. No manipulation of stick or throttle is required; however, throttle control is available to adjust altitude if necessary. Communication between the aircraft controller and mission controller is ongoing and the mission controller continues to monitor system status. Both the aircraft controller and the mission controller begin "heads up" flying upon the AV's approach to their location, at which time, flight mode is deviated or landing procedures are initiated.

### 2.2.3 Workload

Each function completed by either the aircraft controller or the mission controller has a number of tasks associated with it. For example, two tasks under the function for launch for the aircraft controller include throttle up and monitor flight path, while two of the mission controller tasks include the physical launch of the AV and monitoring of system status. In order to accomplish any task, the aircraft controller and the mission controller must use certain interfaces. Interfaces are aspects of the system, which the operator uses to accomplish a task. These interfaces include the GCU display, the AV, the horizon, the other crew member, the throttle toggle, the joystick, and any buttons. For example, the aircraft controller interfaces with the other crew member

when he communicates with the mission controller while operating the UAV.  In another example, the aircraft controller interfaces with the toggle and GCU display when he adjusts the AV's speed.  For each task, the model simulates the amount of workload required to perform a task by tracking which attentional resources are used while a given interface is manipulated to perform a particular task.  The attentional resources which an operator can use to perform any task are visual, auditory, cognitive, speech, and motor resources.  For example, the aircraft controller uses his motor resource to move the throttle toggle to the up position during launch. Once each interface was matched with the resources used to perform a given task, the estimated amount of operator workload was determined by SMEs.  These SMEs choose the level of workload derived from a set of five scales built into IMPRINT.  SMEs determine workload through questions such as, "When I physically move the throttle toggle to the up position, how much visual workload am I using to look at the display? or the AV? or the throttle?, etc." or "When I physically move the throttle toggle to the up position, how much auditory workload am I using to hear the AV?  or the other crew member?, etc."  Once all tasks have been assigned workload values, IMPRINT can calculate the mental workload required to perform the tasks for a two-person crew to operate the Raven SUAV.

## 3. Results

This operator model of Raven SUAV operations serves as a general representation of normal operating procedures.  This model did not attempt to examine different crew or system configurations.  It is simply a model of a detailed task analysis in an effort to accurately portray the workload required to operate the Raven SUAV.  The specifics of the workload will be further examined when combined with numerous FCS models as a whole.  For this project, a very brief look at the workload of the tasks and functions was reviewed.

During normal operating conditions, a two-person team consisting of an aircraft controller and a mission controller would operate a Raven SUAV.  This two-person team would operate the Raven SUAV in one of the available five flight modes.  As previously discussed, a number of tasks are associated with operating the Raven SUAV within each mode.  This model of normal operations of the Raven SUAV used each mode of operations a randomly drawn number of times in an effort to capture workload within each mode.  For example, within this model run, the manual mode of operations was used eight times.

Most of the time when Soldiers do their jobs, they are often multi-tasking to accomplish the mission.  Any tasks that they are currently engaged in require mental effort.  Although there are some penalties for using the same resource for concurrent tasks, generally speaking, when the effort from each task is added to each other, the result is the mental workload required to accomplish a set of tasks.  An individual is considered to be in high workload when his or her

mental workload exceeds 60. Research indicates that errors are more likely to occur during periods of high workload (Rueb, Vidulich, & Hassoun, 1992); (Reid & Colle, 1998). This workload model ran in the manual mode for 13 minutes and 55 seconds, followed closely by navigating waypoints mode and loiter mode with 12.28 and 12.17, respectively. There were 798 instances of high workload for the aircraft controller during manual mode, 87 instances of high workload during navigating waypoints mode, 89 instances of high workload during the loiter mode, and 106 instances of workload during the altitude mode. The results of the operator workload model indicate that high workload was more prevalent for the aircraft controller during manual mode than in any other mode. This demonstrates the model's face validity since it is consistent with real life operations in that more tasks are required during manual mode and thus more workload would be imposed on the user.

Table 2. Time and instances of high workload in each mode.

| | **Time in Mode** | **High Workload** |
|---|---|---|
| Manual Mode | 13.55 | 798 |
| Navigating Waypoints Mode | 12.28 | 87 |
| Loiter Mode | 12.17 | 89 |
| Altitude Mode | 6.49 | 106 |

It is important to note that although an individual may be considered to be in high workload, it does not necessarily mean that the individual cannot accomplish the task. It just means that these are the times in which an individual's workload exceeds the threshold of 60, which is considered to be the level at which mistakes are more likely to occur (Rueb, Vidulich, and Hassoun, 1992).

## 4. Discussion

Keeping in mind that this model did not attempt to examine different crew or system configurations and that this model serves as a general representation of normal operating procedures for the Raven SUAV, the results seem to indicate that workload is at its highest when the AV is in the manual mode of operations. These findings are consistent with the real world in that the number of tasks associated with operating the Raven SUAV in the manual mode of operations are greater than those of any other mode. This general representation of normal operating procedures for the Raven SUAV demonstrates the ability to predict levels of workload while operating this or any current system as well as the workload associated with operating future systems in development and even those still in the concept phase.

### 4.1 Current Systems

Systems already being used in theater such as the Raven SUAV and Shadow 200 tactical UAV can use the knowledge that this IMPRINT modeling technique provides to examine current

Soldier workload and possibly change current doctrine with new or modified tactics, techniques, and procedures (TTPs), a possible reallocation of functions between crew members and/or the system, an introduction of new training techniques or selection criteria, and may even suggest systems revisions that may enhance performance.

### 4.1.1 Tactics, Techniques, and Procedures (TTPs)

Systems already fielded can use this knowledge to create additional TTPs that would effectively reduce workload and enhance performance. For example, when the UAV team is conducting convoy security, they follow a convoy. This mission would be accomplished in the manual mode of operations. Over-flying a convoy while in the manual mode of operations is not uncommon. Once the AV has over-flown the convoy, the AC must then circle back in an effort to re-obtain the convoy in the video window. This circling back has two drawbacks. First and foremost, the UAV team and consequently the tactical operations center (TOC), have lost eyes on the convoy which hinders situational awareness. In addition, the tasks associated with maneuvering the AV back to the convoy have increased the workload of the UAV team. A new TTP would help to reduce overall workload and enhance performance. This TTP might be that when the AV is following a convoy, it is imperative that the master chief continuously communicate with the lead vehicle to ascertain the speed at which the convoy is traveling. This reduces the workload of the AC by eliminating the need to circle back as well eliminating the loss of SA.

### 4.1.2 Function Reallocation

Another area in which this modeling technique could improve performance is function reallocation. This model indicated findings of high workload for the aircraft controller during manual mode of operations. A suggestion might be that when the aircraft controller is operating in the manual mode of operations, the mission controller must now assume the task of searching and scanning the live video and must assume communications to and from the TOC in an effort to evenly distribute the workload and decrease the likelihood of a mistake being made. Another reallocation of function idea may be that the task of periodic manipulation of the stick to control for wind of the AV during navigating waypoints and loiter modes of operation should be reallocated to a computer system integrated into the GCU, which will automatically make the slight adjustments needed to ensure that the AV is on course as directed. This reallocation of tasks from the AC to an on-board computer system capable of making the necessary adjustments could decrease workload for the AC and again decrease the likelihood of mistakes being made.

### 4.1.3 Training and/or Operator Characteristics

These model findings may also lead to identifying training and/or operator characteristics and how they may correlate to performance. For example, when the MC changes a waypoint "on the fly," he must know where he is on the map, know where the AV is on the map, and know where the new waypoint will be on the map, all with in a matter of seconds. This skill set takes a high

amount of cognitive and visual workload to accomplish. An operator characteristic may be that it is imperative that a UAV operator have good map reading skills.

#### 4.1.4 System Revisions

Finally, the findings in this or similar models may lead to possible system revisions that would enhance system performance. As previously mentioned, the addition of an on-board computer system capable of making slight adjustments in the AV's flight path may decrease workload for the operators and as a result possibly decrease the likelihood of mistakes being made. An IMPRINT model could also be designed to compare the workload associated with operating the AV with the current GCU configuration against newer, smaller, and more compact GCUs, possibly a personal digital assistant (PDA)-sized GCU. A GCU the size of a PDA would certainly be easier to carry and may provide the Soldier with the ability to holster the PDA briefly on his person, which would free his hands to possibly accomplish another task but at what cost? With the entire GCU the size of a PDA, the liquid crystal display would have to be nearly half the size it currently is, probably making it more difficult to see, and although the idea of holstering the GCU for a brief period of time in order to accomplish another task might seem valuable, the loss of situational awareness might not be worth it. In the time it would take for the operator to gain situational understanding once he picks up the GCU again might be the difference in locating the enemy or flying right by him. All these questions could be examined through IMPRINT modeling which is certainly more cost effective than revising a system only to find that it causes more problems than it helps.

### 4.2 Future Systems

The ability to have this knowledge will enhance system development from the concept phase to system fielding. Systems in the development or concept phases can use this knowledge to predict where errors might occur, where performance may fail and to ascertain whether a new technology might produce too high of a workload situation for its operators. Modeling in this manner also allows a way to easily look at workload demands for Soldiers where multi-tasking has become the norm.

Future modeling efforts should continue to examine the Soldier workload of current and future UAV systems in an effort to assist in reducing high workload situations by affecting such things as TTPs, task reallocation, training and operator characteristics, system revisions, as well as systems in the concept and development phases.

- What was learned about CoHOST
- What can be done to improve CoHOST
- New directions for CoHOST and the methodology
    - Functional modules as opposed to organizational modules.
    - Enhanced SME input and expansion of JASS database

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# Appendix A. Tables

Table A-1. Resources and interfaces key.

| Resources and Interfaces Resource-Interface Pairs | | |
|---|---|---|
| **Resources** | **Interfaces** | **Resource-Interface Pairs** |
| Visual | Display | VD = Visual Display |
| | AV | VA = Visual Air Vehicle |
| | Horizon | VH = Visual Horizon |
| | | |
| Auditory | AV | AA = Auditory Air Vehicle |
| | Crewmember | AC = Auditory Crewmember |
| | | |
| Motor | AV | MA = Motor Air Vehicle |
| | Throttle | MT = Motor Throttle |
| | Joystick | MJ = Motor Joystick |
| | Button | MB = Motor Button |
| | | |
| Speech | Crewmember | SC = Speech Crewmember |
| | | |
| Cognitive | Display | CD = Cognitive Display |
| | AV | CA = Cognitive Air Vehicle |
| | Crewmember | CC = Cognitive Crewmember |
| | Throttle | CT = Cognitive Throttle |
| | Joystick | CJ = Cognitive Joystick |
| | Button | CB = Cognitive Button |

Table A-2. Aircraft controller task list.

| Aircraft Controller | | Resources and Interfaces | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Functions** | **Tasks** | VD | VA | VH | AA | AC | MT | MA | MB | MJ | SC | CT | CD | CB | CJ | CC | CA |
| Launch | Throttle Up | | | | 1 | | 1 | | | | | 1 | | | | | |
| Launch | Monitor Flight Path | | 1 | | | | | | | | | | | | | | 1 |
| Launch | Look Away Path | | | 1 | | | | | | | | | | | | | |
| Launch | Back Stick | | | | | | | | | 1 | | | | | 1 | | |
| Launch | Release Back Stick | | | | | | | | | 1 | | | | | 1 | | |
| Launch | Emergency Autoland | | | | | | | | 1 | | | | | 1 | | | |
| Launch | Throttle Neutral | | | | | | 1 | | | | | 1 | | | | | |
| Launch | Mode Selection | | | | | | | | 1 | | | | | 1 | | | |
| Launch | Communicate | | | | | 1 | | | | | 1 | | | | | 1 | |
| Manual Mode | Stick Control to maneuver laterally | | | | | | | | | 1 | | | | | 1 | | |
| Manual Mode | Toggle Throttle to control altitude | | | | | | 1 | | | | | 1 | | | | | |
| Manual Mode | Communicate | | | | | 1 | | | | | 1 | | | | | 1 | |
| Manual Mode | Deviate Mode | 1 | | | | | | | 1 | | | | 1 | 1 | | | |
| Manual Mode | Maintain Stick Position | | | | | | | | | 1 | | | | | 1 | | |
| Manual Mode | Maintain Throttle position | | | | | | 1 | | | | | 1 | | | | | |
| Manual Mode | Identify Potential Interest | 1 | | | | | | | | | | | 1 | | | | |
| Manual Mode | Monitoring Intensifies | 1 | | | | | | | | | | | 1 | | | | |
| Manual Mode | Communication Intensifies | | | | | 1 | | | | | 1 | | | | | 1 | |
| Manual Mode | Decide on Mode | | | | | | | | | | | | 1 | | | | |
| Manual Mode | Monitor Flight Path | 1 | | | | | | | | | | | 1 | | | | 1 |
| Manual Mode | Look Away Path | | | 1 | | | | | | | | | | | | | |
| Manual Mode | Search/Scan | 1 | | | | | | | | | | | 1 | | | | |
| Manual Mode | Look Away SS | | | 1 | | | | | | | | | | | | | |
| Altitude mode | Stick Control to maneuver laterally | | | | | | | | | 1 | | | | | 1 | | |
| Altitude mode | Maintain Stick Position | | | | | | | | | 1 | | | | | 1 | | |
| Altitude mode | Communicate | | | | | 1 | | | | | 1 | | | | | 1 | |
| Altitude mode | Identify Potential Interest | 1 | | | | | | | | | | | 1 | | | | |
| Altitude mode | Monitoring Intensifies | 1 | | | | | | | | | | | 1 | | | | |
| Altitude mode | Communication Intensifies | | | | | 1 | | | | | 1 | | | | | 1 | |
| Altitude mode | Decide on Mode | | | | | | | | | | | | 1 | | | | |
| Altitude mode | Deviate Mode | | | | | | | | 1 | | | | | 1 | | | |
| Altitude mode | Search/Scan | 1 | | | | | | | | | | | 1 | | | | |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Altitude mode | Look Away SS | | | 1 | | | | | | | | | | | | | |
| Altitude mode | Monitor Flight Path | 1 | | | | | | | | | | | 1 | | | | 1 |
| Altitude mode | Look Away Path | | | 1 | | | | | | | | | | | | | |
| Loiter Mode | Periodic Stick Control to maneuver laterally | | | | | | | | | 1 | | | | | 1 | | |
| Loiter Mode | Communicate | | | | | 1 | | | | | 1 | | | | | 1 | |
| Loiter Mode | Identify Potential Interest | 1 | | | | | | | | | | | 1 | | | | |
| Loiter Mode | Monitoring Intensifies | 1 | | | | | | | | | | | 1 | | | | |
| Loiter Mode | Communication Intensifies | | | | | 1 | | | | | 1 | | | | | 1 | |
| Loiter Mode | Decide on Mode | | | | | | | | | | | | 1 | | | | |
| Loiter Mode | Deviate Mode | | | | | | | | 1 | | | | | 1 | | | |
| Loiter Mode | Periodic Throttle to Control Altitude | | | | | | 1 | | | | | 1 | | | | | |
| Loiter Mode | Monitor Flight Path | 1 | | | | | | | | | | | 1 | | | | 1 |
| Loiter Mode | Look Away Path | | | 1 | | | | | | | | | | | | | |
| Loiter Mode | Search/Scan | 1 | | | | | | | | | | | 1 | | | | |
| Loiter Mode | Look Away SS | | | 1 | | | | | | | | | | | | | |
| Loiter Mode | Enter POI Grid | 1 | | | | | | | 1 | | | | 1 | 1 | | | |
| Home Mode | Select Home Mode | 1 | | | | | | | 1 | | | | 1 | 1 | | | |
| Home Mode | Communicate | | | | | 1 | | | | | 1 | | | | | 1 | |
| Home Mode | Deviate Mode | | | | | | | | 1 | | | | | 1 | | | |
| Home Mode | Eyes of AV Before Landing | | 1 | | 1 | | | | | | | | | | | | 1 |
| Home Mode | Monitor Flight Path | 1 | | | | | | | | | | | 1 | | | | 1 |
| Home Mode | Look Away Path | | | 1 | | | | | | | | | | | | | |
| Home Mode | Search/Scan | 1 | | | | | | | | | | | 1 | | | | |
| Home Mode | Look Away SS | | | 1 | | | | | | | | | | | | | |
| Home Mode | Identify Potential Interest | 1 | | | | | | | | | | | 1 | | | | |
| Home Mode | Monitoring Intensifies | 1 | | | | | | | | | | | 1 | | | | |
| Home Mode | Communication Intensifies | | | | | 1 | | | | | 1 | | | | | 1 | |
| Home Mode | Decide on Mode | | | | | | | | | | | | 1 | | | | |
| Navigating Way points Mode | Periodic Throttle to Control Altitude | | | | | | 1 | | | | | 1 | | | | | |
| Navigating Way points Mode | Communicate | | | | | 1 | | | | | 1 | | | | | 1 | |
| Navigating Way points Mode | Identify Potential Interest | 1 | | | | | | | | | | | 1 | | | | |
| Navigating Way points Mode | Monitoring Intensifies | 1 | | | | | | | | | | | 1 | | | | |
| Navigating Way points Mode | Communication Intensifies | | | | | 1 | | | | | 1 | | | | | 1 | |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Navigating Way-points Mode | Decide on Mode | | | | | | | | | | | | 1 | | | | |
| Navigating Way-points Mode | Deviate Mode | | | | | | | | 1 | | | | | 1 | | | |
| Navigating Way-points Mode | Monitor Flight Path | 1 | | | | | | | | | | | 1 | | | | 1 |
| Navigating Way-points Mode | Look Away Path | | | 1 | | | | | | | | | | | | | |
| Navigating Way-points Mode | Search/Scan | 1 | | | | | | | | | | | 1 | | | | |
| Navigating Way-points Mode | Look Away SS | | | 1 | | | | | | | | | | | | | |
| Landing | Monitor Flight Path | 1 | | | | | | | | | | | 1 | | | | 1 |
| Landing | Look Away Path | | | 1 | | | | | | | | | | | | | |
| Landing | Locate AV in Sky | | 1 | | 1 | | | | | | | | | | | | 1 |
| Landing | Position AV 100 ft AGL into wind | | 1 | | 1 | | | | | | | | | | | | 1 |
| Landing | Communicate | | | | | 1 | | | | | 1 | | | | | 1 | |
| Landing | Periodic Stick Control to maneuver laterally | | | | | | | | | 1 | | | | | 1 | | |
| Landing | Fly Heads Up with Eyes on AV | | 1 | | 1 | | | | | | | | | | | | 1 |
| Landing | Autoland | | 1 | | 1 | | | | 1 | | | | | 1 | | | 1 |
| Pre Flight | Assembly | | 1 | | 1 | | | 1 | | | | | | | | | 1 |
| Pre Flight | Pre Flight Checks | 1 | | | | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Post Flight | Inspection | | 1 | | | | | 1 | | | | | | | | | 1 |
| Post Flight | Disassembly | | 1 | | | | | 1 | | | | | | | | | 1 |
| | | 25 | 9 | 12 | 7 | 13 | 7 | 3 | 11 | 9 | 13 | 7 | 30 | 11 | 9 | 13 | 16 |
| **9 Functions** | **83 Tasks** | | | | | | | | | | | | | | | **195 Data Points** | |

Table A-3. Mission controller task list.

| Mission Controller | | Resources and Interfaces | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Functions | Tasks | VD | VA | VH | AA | AC | MT | MA | MB | MJ | SC | CT | CD | CA | CC | CB | CJ | |
| Launch | Physical Launch | | 1 | 1 | 1 | 1 | | 1 | | | 1 | | | 1 | 1 | | | 8 |
| Launch | Monitor System Status | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Launch | Look Away Status | | | 1 | | | | | | | | | | | | | | 1 |
| Launch | Communicate | | | | | 1 | | | | | 1 | | | | 1 | | | 3 |
| Manual Mode | Monitor System Status | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Manual Mode | Communicate | | | | | 1 | | | | | 1 | | | | 1 | | | 3 |
| Manual Mode | Look Away Status | | | 1 | | | | | | | | | | | | | | 1 |
| Manual Mode | Identify Potential Interest | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Manual Mode | Monitoring Intensifies | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Manual Mode | Communication Intensifies | | | | | 1 | | | | | 1 | | | | 1 | | | 3 |
| Manual Mode | Decide on Mode | | | | | | | | | | | | 1 | | | | | 1 |
| Manual Mode | Search/Scan | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Manual Mode | Look Away SS | | | 1 | | | | | | | | | | | | | | 1 |
| Altitude Mode | Communicate | | | | | 1 | | | | | 1 | | | | 1 | | | 3 |
| Altitude Mode | Look Away Status | | | 1 | | | | | | | | | | | | | | 1 |
| Altitude Mode | Monitor System Status | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Altitude Mode | Identify Potential Interest | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Altitude Mode | Monitoring Intensifies | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Altitude Mode | Communication Intensifies | | | | | 1 | | | | | 1 | | | | 1 | | | 3 |
| Altitude Mode | Decide on Mode | | | | | | | | | | | | 1 | | | | | 1 |
| Altitude Mode | Search/Scan | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Altitude Mode | Look Away SS | | | 1 | | | | | | | | | | | | | | 1 |
| Loiter Mode | Communicate | | | | | 1 | | | | | 1 | | | | 1 | | | 3 |
| Loiter Mode | Monitor System Status | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Loiter Mode | Look Away Status | | | 1 | | | | | | | | | | | | | | 1 |
| Loiter Mode | Identify Potential Interest | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Loiter Mode | Monitoring Intensifies | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Loiter Mode | Communication Intensifies | | | | | 1 | | | | | 1 | | | | 1 | | | 3 |
| Loiter Mode | Decide on Mode | | | | | | | | | | | | 1 | | | | | 1 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Loiter Mode | Search/Scan | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Loiter Mode | Look Away SS | | | 1 | | | | | | | | | | | | | | 1 |
| Home Mode | Communicate | | | | | 1 | | | | | 1 | | | | 1 | | | 3 |
| Home Mode | Monitor System Status | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Home Mode | Look Away Status | | | 1 | | | | | | | | | | | | | | 1 |
| Home Mode | Search/Scan | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Home Mode | Look Away SS | | | 1 | | | | | | | | | | | | | | 1 |
| Home Mode | Identify Potential Interest | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Home Mode | Monitoring Intensifies | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Home Mode | Communication Intensifies | | | | | 1 | | | | | 1 | | | | 1 | | | 3 |
| Home Mode | Decide on Mode | | | | | | | | | | | | 1 | | | | | 1 |
| Navigating Waypoints Mode | Communicate | | | | | 1 | | | | | 1 | | | | 1 | | | 3 |
| Navigating Waypoints Mode | Monitor System Status | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Navigating Waypoints Mode | Look Away Status | | | 1 | | | | | | | | | | | | | | 1 |
| Navigating Waypoints Mode | Identify Potential Interest | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Navigating Waypoints Mode | Monitoring Intensifies | | | | | | | | | | | | 1 | | | | | 1 |
| Navigating Waypoints Mode | Communication Intensifies | | | | | 1 | | | | | 1 | | | | 1 | | | 3 |
| Navigating Waypoints Mode | Decide on Mode | | | | | | | | | | | | 1 | | | | | 1 |
| Navigating Waypoints Mode | Change a Waypoint | 1 | | | | | 1 | | 1 | 1 | | 1 | 1 | | | 1 | 1 | 8 |
| Navigating Waypoints Mode | Search/Scan | 1 | | | | | | | | | | | 1 | | | | | 2 |
| Navigating Waypoints Mode | Look Away SS | | | 1 | | | | | | | | | | | | | | 1 |
| Landing | Locate AV in Sky | | 1 | | 1 | | | | | | | | | | | | | 2 |
| Landing | Communicate | | | | | 1 | | | | | 1 | | | | 1 | | | 3 |
| Landing | Communicate ALT and Bearing | | | | | 1 | | | | | 1 | | | | 1 | | | 3 |
| Landing | Eyes on AV | | 1 | | | | | | | | | | | | | | | 1 |
| Pre Flight | Assembly | | 1 | | | | | 1 | | | | | | 1 | | | | 3 |
| Pre Flight | Waypoint Entry | 1 | | | | | 1 | | 1 | 1 | | 1 | 1 | | | 1 | 1 | 8 |
| Pre Flight | Pre Flight Checks | | 1 | | | | | 1 | | | 1 | | | 1 | 1 | | | 5 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Post Flight | Recovery | | 1 | | 1 | 1 | | 1 | | | | | | 1 | | | | 5 |
| Post Flight | Inspection | | 1 | | | | | 1 | | | | | | 1 | | | | 3 |
| Post Flight | Disassembly | | 1 | | | | | 1 | | | | | | 1 | | | | 3 |
| | | 22 | 8 | 12 | 3 | 15 | 2 | 6 | 2 | 2 | 15 | 2 | 28 | 6 | 15 | 2 | 2 | 142 |
| **9 Functions** | **61 Tasks** | | | | | | | | | | | | | | | | **142 Data Points** | |

Table A-4. Resource scales.

| **Resource Scales** | |
|---|---|
| **Visual** | |
| 3.0 | Visually Register/Detect (Detect Occurrence of Image) |
| 5.0 | Visually discriminate (Detect Visual Differences) |
| 3.0 | Visually Inspect/Check (Discrete Inspection/Static Condition) |
| 4.0 | Visually Locate/Align (Selective Orientations) |
| 4.4 | Visually Track/Follow (Maintain Orientation) |
| 6.0 | Visually Scan/Search Monitor (Continuous/Serial Inspection) |
| 5.0 | Visually Read (Symbol) |
| | |
| **Auditory** | |
| 1.0 | Detect/Register Sound (Detect Occurrence of Sound) |
| 2.0 | Orient to Sound (General Orientation/Attention) |
| 4.2 | Orient to Sound (Selective Orientation/Attention) |
| 4.3 | Verify Auditory Feedback (Detect Occurrence of Anticipated Sound |
| 3.0 | Interpret Semantic Content (Speech) Simple 3 (1-2 Words) |
| 6.0 | Interpret Semantic content (Speech) Complex 6 (Sentence) |
| 6.6 | Discriminate Sound Characteristics (Detect Auditory Difference) |
| 7.0 | Interpret Sound Patterns (Pulse Rates, etc.) |
| | |
| **Motor** | |
| 2.2 | Discrete Actuation (Button, Toggle, Trigger) |
| 2.6 | Continuous Adjustive (Flight Control, Sensor Control) |
| 4.6 | Manipulative |
| 5.5 | Discrete Adjustment (Rotary, Vertical Thumb Wheel, Lever Position) |
| 6.5 | Symbolic Production (Writing) |
| 7.0 | Serial Discrete Manipulation (Keyboard) |
| | |
| **Speech** | |
| 2.0 | Simple (1-2 Words) |
| 4.0 | Complex (Sentence) |
| | |
| **Cognitive** | |
| 1.0 | Automatic (Simple Association) |
| 1.2 | Alternative Selection |
| 3.7 | Sign/Signal Recognition |
| 4.6 | Evaluation/Judgment (Consider Single Aspect) |
| 5.3 | Encoding/Decoding, Recall |
| 6.8 | Evaluation/Judgment |
| 7.0 | Estimation, Calculation, Conversion |
| 5.0 | Rehearsal |

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